

“On the Chief Line in the Spectrum of the Nebulæ.” By  
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- I. Introductory.
- II. The accuracy attainable in these inquiries.
- III. Wave-length of the chief nebula line.
  - A. Historical notice.
  - B. Laboratory observations with high dispersion in connexion with the chief nebula line.
  - C. Observations by a new method.
- IV. Fluted character of the chief nebula line.
- V. Conclusion.

#### I. INTRODUCTORY.

In 1887, reasoning from the spectral phenomena in stars of Vogel's Class IIIa, which my researches proved to be due to the mixture of bright flutings of carbon and dark flutings of manganese and other substances, I came to the conclusion that these stars could not be stars in the ordinary sense but swarms of bodies separated from each other.

I next showed, reasoning again from the spectral phenomena, that these bodies were in all probability meteorites or particles of meteoritic dust.

A discussion of the origin of such stars as these next suggested that it must be sought for in the nebulæ. Meteoritic dust was then experimented upon and two lines of unknown origin in the spectrum of this dust were found to be roughly in the same position as two lines of unknown origin in the nebula spectrum.

In my first communication to the Royal Society on this subject I stated that the conclusions were “given with great reserve,” and I was careful to point out that I had limited myself to small dispersion (1 prism of 60°), because it was imperative that all the observations should be strictly comparable; those of very faint glows visible with difficulty and those of a bright electric arc, to speak only of laboratory work; and I also added that there was an additional reason for this in the difficulty of obtaining astronomical observations with large dispersions in the case of very dim celestial objects.

Seeing, therefore, that I dealt only, of set purpose, with small dispersion, I limited myself to a “short title” of three figures in my references to the lines.

But, although I did not employ great dispersion in the first instance, I fully understood that this must be done eventually, so I at

once provided for such observations both in laboratory and observatory, and they were commenced last May.

So far, however, only one branch of the observatory work has been commenced, in consequence of delays on the part of the instrument maker. I should here state that my main endeavour in one direction will be to obtain photographs of the spectra of nebulae and reference spectra under such conditions that any instrumental error will register itself on the plate in such a way that a proper correction for it can be made. For such work as this much light and great stability are required; I have therefore erected a 30-inch reflector at Westgate-on-sea, having received a grant in aid from the Government Grant Fund; the mirror has been figured and presented to me by my friend Mr. Common; the flat (7 inch diameter) by other friends, the Brothers Henry, and I am anxious to take this opportunity of expressing my obligations to them for this magnificent help in my work.

The laboratory researches, consisting of the application of higher dispersion, have made more progress; but they are not yet finished, and in this paper I shall confine myself to observations made with reference to the chief nebula line.

A paper by Dr. and Mrs. Huggins, which has appeared in the 'Proceedings' during the recess, contains criticisms of some points in my recent papers which require a reply. They hold that I am wrong in my identification of the origin of some lines in the spectrum of the nebulae, chiefly those two which Dr. Huggins himself has formerly ascribed in one case to an unknown form of nitrogen and in the other to hydrogen under some conditions which we cannot match in the laboratory; I, on the other hand, suggesting that possibly they may be produced by magnesium, a substance which occurs in most meteorites.

I gather from this paper of Dr. and Mrs. Huggins that my object in using a three-figure reference to the lines has been misunderstood. I think it important, therefore, that I should at the present time return to the subject, giving my reasons for the three-figure references I used in the first instance. For this purpose it is necessary to state the history of the subject less eclectically than Dr. and Mrs. Huggins have done. I shall then give the work that has been since accomplished, though, as I have stated above, it is not yet finished; and reply to Dr. and Mrs. Huggins's criticisms as best I can.

As in my replies to the various objections raised by Dr. and Mrs. Huggins, I am most anxious not to even unconsciously misrepresent their views, I shall deal with each line separately, take each objection *seriatim*, and give their own words as far as possible. I confine myself in the present paper to that at  $\lambda$  500.

I am extremely gratified to find that in an inquiry dealing with, roughly, some 10,000 observations, which has taken me two years, and the details of which occupy some 235 pages in the 'Proceedings,' the point in my argument to which Dr. and Mrs. Huggins take exception is a subsidiary one.

## II. THE ACCURACY ATTAINED IN EARLIER INVESTIGATIONS.

My astronomical work has so far been almost exclusively devoted to the Sun, in which case considerable dispersion is easily utilised. When my Sun work drove me to try to obtain some information from other celestial bodies, I had to enter a comparatively unfamiliar field of observation. It may well be, therefore, that I ignorantly over-estimated the difficulties of such observations, and a passage in Dr. and Mrs. Huggins's paper seems to suggest that such is the case. They refer to observations of nebulæ with a dispersion approaching that given by 8 prisms of  $60^\circ$ , with the Royal Society telescope. It must be pointed out, however, that although this instrument has been in Dr. Huggins's possession for nearly twenty years, so far as I know no such observations have been continuously made with it previously, or indeed by any other instruments in the hands of any other observers. I was justified in this view by noting that in Dr. Huggins's important research published in 1879 only one prism was employed in obtaining the photographic spectra of some of the brightest stars in the heavens, made with the same telescope, and that some two years afterwards, in 1881, he wrote, with reference to some observations made by him of the comet of that year:—"I am also able to see upon the continuous solar spectrum a distinct impression of the group of lines between G and *h* which is usually associated with the group described above. My measures for the less refrangible group give a wave-length of 4230, which agrees, as well as can be expected, with Professor Liveing and Dewar's measures, 4220."\* A diagram of the spectrum of the comet was published in the paper in which this passage occurs, to which some importance seems to have been attached.

As, judging from this, the position of the lines in question could have been read to about two in the fourth place, I am justified in regarding this statement as a practical use of a three-figure reference. I gather from Dr. and Mrs. Huggins's criticism that Dr. Huggins now expresses wave-lengths by five figures, that is, he states wave-lengths to the hundred-millionth of a millimetre. It is convenient, therefore, to express the discrepancies between different measurements in terms of this quantity as a unit. It will be seen that in 1881 he accepted with complacency a variation of 100 units of such

\* 'Roy. Soc. Proc.,' vol. 33, p. 2.

a scale in the measurements made in the laboratory and observatory respectively of a line which his diagram shows as clearly defined, though in the text he uses the ambiguous phrase that he was able to see a "distinct impression" of it. He did not consider that a discrepancy of the magnitude indicated threw any doubt upon the identity of the lines.

I may mention as another fact which supports the use of a three-figure reference, that even in the research on the brightest stars it was difficult to absolutely reconcile the one-prism work in the observatory with laboratory work. No better illustration of this could be found than a comparison of the work of two such observers as Dr. Huggins and Prof. Cornu.

One of the chief points in the memoir was the discovery of a series of lines in the ultra-violet which Dr. Huggins ascribed to hydrogen; lines near the position given have, indeed, since been measured in hydrogen by Cornu.\* I append the wave-lengths as given by the two observers:—

Huggins.†		Cornu.
3767·5	....	3769·4
3745·5	....	3749·8
3730·0	....	3733·6
3717·5	....	3720·6
3707·5	....	3710·7
3699·0		

It will again be observed, that if one had wished to give a handy reference to these lines—a short title—three figures would have been sufficient in two cases, for we have—

3717·5	....	3720·6
3707·5	....	3710·7

It is no part of my present business, however, to discuss the relative accuracy of Dr. Huggins and Prof. Cornu as observers, but it must be pointed out that by the nature of the research Prof. Cornu is more likely to be right. We owe one of our best maps of the solar spectrum in this part to Prof. Cornu, and the comparison of hydrogen with the Sun could always be repeated at leisure and under stable conditions, whereas, in the case of Dr. Huggins, the result depended upon a photographic solar comparison in the telescope taken some hours afterwards. In any case, Professor Cornu's numbers are three years old, and, so far as I know, Dr. Huggins has not challenged them.

An inspection of the numbers shows that there is, in all probability,

\* 'Journal de Physique,' vol. 10, 1886, 341.

† 'Phil. Trans.,' vol. 171, p. 682.

a systematic error in Dr. Huggins's results of about thirty of the units suggested above, and anyone acquainted with spectroscopic work will see how very easily this might arise from the absence of perfect adjustment.

This brings me to another point which also influenced me in arriving at the view I held, however erroneously.

For the last fifteen years I have been employed, among other matters, in taking photographs of the solar spectrum compared with arc spectra. Of the thousands of photographs taken (with a dispersion such that the distance between H and K covers about half an inch on the plate) many hundreds have been rejected on account of the want of exact coincidence between the solar and terrestrial lines of the same element, the slightest variation in the rate of the clock of the heliostat or siderostat employed, or the occasional changing of the arc from the centre to either side of the pole, being enough to produce this result.

Hence, when I wrote my paper of November, 1887, I held (and I still hold, although I may have erred in overrating the difficulty of observing stellar and nebular spectra) that short titles of the lines compared, extending to three figures, sufficiently refer to positions, and do not really underestimate the accuracy generally attainable. Indeed, if this be not so, then from the single instance I have quoted Dr. Huggins's classic paper on the spectra of the white stars is misleading, and his series of lines in the ultra-violet cannot be due to hydrogen.

These general remarks being premised, I next give in historical sequence the observations of the nebula line now in question.

### III. WAVE-LENGTH OF THE CHIEF NEBULA LINE.

#### A. *Historical Notice.*

Dr. Huggins's considers the nebulæ to be masses of gas, and he has suggested that the chief nebula line may owe its origin to some unknown form of nitrogen.

When I commenced my experiments on meteoritic glows, I saw a line in the position of the chief nebula line, with the dispersion employed. Thinking it might arise from the magnesium in the silicate, I tried terrestrial olivine, and I again saw the line in its spectrum. Subsequent work with a large model Steinheil spectroscope (four prisms and a high power eye-piece) showed that the line was coincident with the least refrangible member of one of the flutings seen in the flame-spectrum of magnesium, the wave-length of which had been given as follows:—

*Lecoq de Boisbaudran .....	5006
†Watts .....	5006·5
‡Liveing and Dewar (1878) ....	5000
§     "             "     (1888) ....	5006·4

Now for the determination of the wave-length of the chief nebula line. I give a condensed statement of the observations available when my paper was written.

(1864):—"The strongest line coincides in position with the brightest of the air lines."|| The diagram which accompanies this description represents the line about midway between the two components of the bright, coarse, nitrogen double. The wave-lengths given by Dr. Watts for the nitrogen lines from a reduction of Dr. Huggins's measures are 4999 and 5003;¶ so that, according to these measures, the wave-length of the nebula line would be somewhere between those positions.\*\* Taking Thalén's measures of the nitrogen lines (5002 and 5005), the position of the nebula line—assuming that it fell according to the drawing—would be 5003·5.

Taking Thalén's measures and Dr. Huggins's reference to the coarse double line, which with the dispersion then used appeared as a single one, the wave-length might be 5002·1 or 5005·1 or any value between these. We have thus a limit of error of thirty units by Thalén's values. Kirchhoff's values for the two lines, as given by Watts, are 5004·6, 5000·6.

1865. Secchi observed the spectrum of the Orion nebula in 1865.††

\* 'Spectres Lumineux,' p. 86.

† 'Phil. Mag.,' 1875, p. 85.

‡ 'Roy. Soc. Proc.,' vol. 27, p. 353.

§ 'Roy. Soc. Proc.,' vol. 44, p. 242.

|| Dr. Huggins, 'Phil. Trans.,' 1864, p. 438.

¶ 'Index of Spectra,' p. 3.

\*\* Dr. and Mrs. Huggins, in their paper, call these figures of Watts into question. They say, "Watts's reduction of my (*sic*) measures to wave-lengths is clearly not accordant with the measures of air-lines immediately preceding and following this line. I have therefore reduced my original measures to wave-lengths, and find for  $N_1$  the value 5004·5—

" Kirchhoff..... 5004·6

" Thalén ..... 5005·1

"Thalén's value is clearly too high, as Thalén gives for the lead line coincident with  $N_1$   $\lambda$ 5004·6 and  $N_1$  is seen on the more refrangible side of the solar iron line given by Ångström as  $\lambda$ 5004·9. In Ångström's map  $N_1$  is laid down on the more refrangible side of the iron line 5004·9 at about 5004·5. The same position is given to  $N_1$  in Kirchhoff's map. I have made a new determination of the position of  $N_1$ , using the second spectrum of a grating 17,300 to the inch, relatively to the solar iron line at 5004·9 according to Ångström. The value came out 5004·6." ('Roy. Soc. Proc.' vol. 46, p. 45.)

†† 'Comptes Rendus,' vol. 60, p. 543.

Three lines were seen, and others suspected. The positions of the lines were only roughly determined even by such an experienced observer. The strongest and widest of the lines was described as situated at two-thirds of the interval between F and b, whilst the second line appeared coincident with F.

1868. An observation made by Dr. Huggins in 1868 reads:—"The determination of the position in the spectrum of the three bright lines was obtained by simultaneous comparison with the lines of hydrogen, nitrogen, and barium. The instrument which I employed had two prisms, each with a refracting angle of  $60^\circ$ , and the positions of the lines were trustworthy within the limits of about the breadth of the double line D . . . . The coincidence of the line in the nebula with the brightest of the lines of nitrogen, though now subjected to a much more severe trial, appeared as perfect as it did in my former observations.\*

It will be noticed that in these observations Dr. Huggins informs us to what extent his observations were trustworthy, and, taking Thalén's measures for D, viz.,

5895.0

5889.0

we find the possible error to be sixty units of the scale above suggested. In the diagram which accompanies the above description the nebula line is shown coincident with the *less* refrangible component of the nitrogen double, in contradistinction to the former observation, which, made with less powerful dispersion and in accordance with Dr. Huggins's estimate of the accuracy attained at that time, placed the line midway between them.

In another paragraph of the same paper (p. 543) Dr. Huggins takes "the wave-length of the nitrogen line at 500.80 millionths of a millimetre." Hence, according to this statement, the nebula line would have a wave-length of 500.80; or 500.51, if Thalén's value for the less refrangible nitrogen line be taken, and by Dr. Huggins's own assertion this value would only be accurate within the interval between the sodium double D, that is, 0006.0. It should also be noticed that the double line of nitrogen is again referred to as if it were a single line.

1868. Lieutenant Herschel made some micrometric measures of the chief nebula line in 1868,† and a reduction of them was made by D'Arrest in 1872, with the following result:—‡

\* 'Phil. Trans.,' 1868, pp. 541-2.

† 'Roy. Soc. Proc.,' vol. 16, p. 451.

‡ 'Undersøgelser over de Nebulosestjerner,' Copenhagen, 1872, p. 22.

Gen. Cat. No.	$\lambda$ of chief line.
1179 Orion neb.	501·7
1567	501·0
2102	500·8
2197	493·4
2581	499·8
2917	500·6
4066	499·8
4361	497·2
4390	504·9
4403	499·8
4407	499·4
4510	504·4
4628	501·9

The mean wave-length given by this series is 500·36, and the extreme values are 493·4—504·9.

1871. The following observations of the line in question were made by Vogel in 1871.\*

Orion nebula, 13th January, 1871 . . . .	500·3
„ „ 19th March, 1871 . . . . .	500·2
General Catalogue 4234 . . . . .	500·5
„ „ 4373 . . . . .	500·7
„ „ 4390 . . . . .	500·5
„ „ 4447 . . . . .	500·7
„ „ 4510 . . . . .	500·8

These measurements differ by no less than 60 units of the scale now adopted; the mean value is 500·53.

1872. Dr. Huggins writes: “The line of nitrogen, when compared with it (the nebula line), appeared double, and each component nebulous, and broader than the line of the nebula. This latter line was seen on several nights to be apparently coincident with the middle of the less refrangible line of the double line of nitrogen.”†

This observation, however, obviously left us in the same position as that of 1868, as far as the wave-length of the nebula line was concerned.

1874. In a paper “On the Motions of some of the Nebulæ towards or from the Earth” communicated to the Society in 1874, Dr. Huggins wrote:—‡

“The brightest line in the nebular spectrum is not sufficiently coincident in character and position with the brightest line in the

\* ‘Bothk. Beob.,’ Leipzig, 1872.

† ‘Roy. Soc. Proc.,’ vol. 20, p. 383.

‡ ‘Roy. Soc. Proc.,’ vol. 22, p. 252.

spectrum of nitrogen to permit this line to be used as a fiducial line of comparison. The line in the spectrum of the nebulæ is narrow and defined, while the line of nitrogen is double, and each component is nebulous and broader than the line of the nebulæ. The nebular line is apparently coincident with the middle of the less refrangible line of the double line of nitrogen\* . . . In the course of some other experiments, my attention was directed to a line in the spectrum of lead which falls upon the less refrangible of the components of the double line of nitrogen. The line appears to meet the requirements of the case, as it is narrow, of a width corresponding to the slit, defined at both edges, and in the position in the spectrum of the brightest of the lines of the nebulæ.

“In December, 1872, I compared this line directly with the first line in the spectrum of the Great Nebula in Orion. I was delighted to find the line sufficiently coincident in position to serve as a fiducial line of comparison.

“I am not prepared to say that the coincidence is perfect; on the contrary, I believe that, if greater prism power could be brought to bear upon the nebulæ, the line in the lead spectrum would be found to be in a small degree more refrangible than the line in the nebulæ.

“The spectroscope employed in these observations contains two compound prisms, each giving a dispersion of  $9^{\circ} 6'$  from A to H. A magnifying power of sixteen diameters was used.

“In the simultaneous observation of the two lines it was found that, if the lead line was made rather less bright than the nebular line, the small excess of apparent breadth of this latter line, from its greater brightness, appeared to overlap the lead line to a very small amount on its less refrangible side, so that the more refrangible sides of the two lines appeared to be in a straight line across the spectrum. This line could be therefore conveniently employed as a fiducial line in the observations I had in view.”

1877. The measures, by Dr. Copeland and Lord Lindsay, of the wave-length of the line near 500 in Nova Cygni, which has generally been accepted as the nebula line, were as follow :—†

1877, January 2	.....	502·4
"      "	.....	505·1
"      "      8	.....	502·9
"      "      9	.....	500·7
"      "      27	.....	500·8
Mean		<hr/> 502·4

\* ‘Roy. Soc. Proc.,’ vol. 20, p. 380.

† ‘Copernicus,’ vol 2, p. 101.

Four additional measurements were made by Dr. Copeland and Lord Lindsay respectively on September 2, 1877. The reduction of the micrometric measures by means of curves gave the following wave-lengths :—

Lord Lindsay.		Dr. Copeland.
499·5	....	498·6
500·1	....	496·2
498·5	....	496·4
499·0	....	497·2
<hr/>		<hr/>
Mean 499·3	....	497·1

Here, again, it is obvious that the wave-length of the line was by no means certain *even to the first three figures*.

1880. Dr. Copeland observed the spectrum of a new planetary nebula in 1880, and obtained the following measures for the chief nebula line :—\*

1880, December 3.....	501·1
„ 6.....	501·2

Dr. Lohse measured the line at 500·6.

The spectrum of the Stephen-Webb nebula was also observed at the same time, and the line measured at 501·9.

From these observations the mean wave-length of the nebula line is found to be 501·2, a value differing widely from that given by Dr. Huggins.

1882. In Dr. Huggins's important paper on the photographic spectrum of the Orion nebula the only reference to the chief line is as follows :†—“The brightest line, wave-length 5005, is coincident with the less refrangible component of the double line which is strongest in the spectrum of nitrogen.” The change of wave-length from 500·80, the value given in 1868, due to a change in the assumed value of the nitrogen line is made without explanation, which shows that Dr. Huggins did not at that time attach as much importance to such variations as he now seems inclined to do. The latest measures of this line, so far as I know, are those given by Dr. Copeland in 1888‡. Although the dispersion employed is not definitely stated, it is remarked that “a sufficiently powerful spectroscope was used.” The measures he gives are as follow :—

1886, December..	5007	Two measures
1887, January....	5003	„ „
1887 „ ....	5003	One measure.

\* ‘Copernicus,’ vol. 1, p. 2.

† ‘Roy. Soc. Proc.,’ vol. 33, p. 427.

‡ ‘Monthly Notices,’ vol. 48, p. 360.

In these observations, therefore, by one of our most skilled spectroscopists, we have a difference of 40 of the units now adopted, and I cannot refrain from pointing out that either the difficulties of the observations or the liability to instrumental error must be very considerable when we see such variations as these, "a sufficiently powerful spectroscope" and the magnificent instrument of Lord Crawford's observatory being employed.

It will be seen from this short retrospect—

(1.) That the mean of the recorded observations of the magnesium fluting placed it at 5004·7, while Dr. Huggins's last description (that I had seen) of the position of the nebula line in terms of wave-length gave 5008·0, as he stated it, or 5005·1, as it may be stated if we take Thalén's value for the nitrogen line. These observations, according to his own statement, were only trustworthy within a limit of sixty units, while the distances from the magnesium fluting are thirty-three and four units respectively, according to which measure of the nitrogen line be taken. From the facts at my disposal, it was obvious that, if any difference existed, the magnesium fluting was more refrangible than the nitrogen line, and therefore than the nebula line, assuming the accuracy of Dr. Huggins's observation of 1868.

(2.) That, if observations by others be considered, the wave-length of the magnesium fluting lies well within the extreme limits; and, indeed, not far from the mean of them all.

From these facts, I trust it will be seen that I was perfectly justified in stating the wave-length of the chief nebula line to three figures only, and, further, that the coincidence between it and the magnesium fluting was sufficiently probable to justify the making of a statement "with reserve" to that effect.

Since my paper of 1887, however, was presented to the Royal Society, I gather from Dr. Huggins's criticisms that he has entirely changed his ideas of the accuracy possible in these inquiries, and now practically withdraws all the statements on which I depended to form an estimate of the amount of accuracy that could be counted upon, and the instrumental means that could be employed, in these researches. As I have shown, the accuracy which Dr. Huggins had attained with all his known skill in his last published observation of the position of the nebula line was trustworthy only within sixty units, according to his own statement; this was in 1868. During the last twenty years, so far as I can make out, this observation has not been improved upon by the more powerful aids to investigation now in his possession, while, on the other hand, as recently as 1881, he regarded with complacency, as I have before stated, a variation of 100 units between the measured place of the same line in laboratory and observatory. Further, in all his impor-

tant work since 1864 Dr. Huggins has employed only one or two prisms as a rule, whilst now he states that he can use a dispersion equal to nearly eight prisms of  $60^\circ$  in the case of the nebula in Orion, and its use implies that this is the minimum dispersion that should be used. I am rejoiced that this is so, if it be so; and future observers, travelling over the ground of which I have attempted to make a rough survey, will no doubt have better observations to work upon than those on which I have depended. But although I am rejoiced that increased dispersion is possible, I am so thoroughly acquainted now with instrumental pitfalls that I cannot accept Dr. and Mrs. Huggins's new value until we know more exactly how it has been obtained, and until many observations, the conditions of which are more fully described, have confirmed it.

Dr. and Mrs. Huggins do not appear to have applied the same test at the same time to the coincidence of the third nebula line with the F line of hydrogen, so that whether the non-coincidence of the magnesium was due to an instrumental error cannot be determined with the facts before us.

The observed difference between the nebula line and the magnesium fluting was nineteen of Dr. Huggins's present units, so that, after all, if we only take his recent observations into account, we have better evidence for the existence of magnesium in the nebulae than we have for hydrogen in the white stars, so far as is evidenced by the lines discovered by Dr. Huggins (see *ante*), for in their case the coincidences do not occur within thirty units.

I next refer to my own observations with high dispersion.

#### B. *Laboratory Observations with High Dispersion in connexion with the Chief Nebula Line.*

Dr. Huggins's observations having led him to the conclusion that the chief nebula line is coincident with the less refrangible member of the double line of nitrogen near 500, and not with the magnesium fluting, I first directed my attention to observations of these lines and flutings in the laboratory, as the arrangements for observatory work with high dispersion were not completed.

The laboratory work was begun last May, and some of the photographic results were exhibited at the Royal Society Soirée in the same month. It was, however, interrupted till the end of July, but since the recess it has been taken in hand again. Dispersions varying from that given by a Liveing direct-vision spectroscope to that of a Rowland grating of 12 feet 10 inches radius and 9.6 square inches surface, with an eyepiece of 1.4 inches equivalent focus, have been employed, in addition to which a Steinheil spectroscope with three or

(in some observations) four prisms and a Cooke spectroscope of sixteen prisms have been used.

The comparisons so far employed by Dr. Huggins in his observations of the chief nebula line are the double green line of nitrogen, a line of lead, and the bright fluting seen in the spectrum of burning magnesium. The relative positions of these have been re-observed in the laboratory.

The exact wave-length of the brightest edge of the magnesium fluting was first determined by means of a comparison photograph of the Sun and burning magnesium.

The dispersion and width of slit were such that practically all the lines seen in Rowland's photographic map were shown in the photograph. There was a slight shift, the amount of which could be determined by measuring the displacement of  $b$ ; when this was allowed for, the wave-length of the magnesium fluting was found to be 5006·5 on Ångström's scale. This has since been confirmed by observations with the four-prism Steinheil and the first order spectrum of the Rowland grating.

Comparison photographs have also been attempted with the Rowland grating, but it was found that even with two hours' exposure only the first four maxima of the magnesium fluting were obtained. It was found difficult to keep the flame of the burning wire sufficiently steady to ensure the light falling directly on the slit during the whole time of exposure.

It may be mentioned here that the secondary maxima of the fluting succeed each other at gradually increasing distances apart. The wave-lengths given by Messrs. Liveing and Dewar\* and those determined from the photographic comparison referred to are as follow:—

Liveing and Dewar.		Lockyer.	
5006·4		5006·5	
	10·8		10·4
4995·6		4996·1	
	10·2		11·0
4985·4		4985·1	
	11·8		11·6
4973·6		4973·5	
	12·0		12·2
4961·6		4961·3	
	13·0		12·9
4948·6		4948·4	
	14·2		14·0
4934·4		4934·4	

The next observations were made with respect to the relative positions of the magnesium fluting and the less refrangible component of

\* 'Roy. Soc. Proc.,' vol. 44, p. 248.

the nitrogen double, which according to Dr. Huggins is coincident with the nebula line. As in his observations of the nebula Dr. Huggins used eight prisms of  $60^\circ$ , the Cooke spectroscope with eight prisms and a telescope magnifying fifteen times was first employed. An electric spark between magnesium electrodes was used, and the length of spark was so adjusted that the nitrogen lines were visible when a Leyden jar was connected with the coil and the magnesium fluting when the jar was taken out of the circuit. The spark was placed about 30 inches in front of the slit, and an image formed by a lens of about 9 inches focus. In this way the chances of error in measurement, due to changes in the direction of the light-source, with respect to the slit, were reduced to a minimum. The spectrum was faint, so that it was found necessary to have the slit rather wide. Under these conditions the magnesium fluting fell on the less refrangible member of the double green air line, as Dr. Huggins observed the nebula line to do in 1868; this was confirmed by my assistants, and was seen by my colleagues Professors Thorpe and Rücker. Twelve and sixteen prisms were subsequently used, and with the wide slit, which it was then necessary to employ, the magnesium fluting still fell on the less refrangible line of nitrogen.

I would here suggest that in future comparisons of the spectra of the nebulae with that of magnesium the quantity spark should be employed for obtaining the fluting, as it is in no way fatiguing to the eye.

This comparison was repeated with a Steinheil spectroscope with three prisms of  $45^\circ$  and a telescope magnifying sixteen times. In this case there was less light lost than with the Cooke spectroscope, and the observations were made with less difficulty.

A small quantity of lead chloride was also introduced into the spark, and the lead line was seen to be slightly more refrangible than the edge of the magnesium fluting, so as to form a close double with it. Using a small jar, it was found possible to obtain together the spectrum of nitrogen, magnesium, and lead superposed, and under these conditions the magnesium fluting was seen still apparently coincident with the less refrangible nitrogen line, and the lead line was a little more refrangible.

The air spark so far employed was that obtained by using a small jar; the nitrogen lines were very fluffy and the spark was so feeble that it was always necessary to use a wide slit.

In subsequent experiments the jar spark between the two platinum poles inserted in a glass tube containing air at a slightly reduced pressure was used. This gave the nitrogen lines very much thinner than the ordinary spark in air, and when a larger jar was put in circuit the spectrum was also brighter. A narrower slit could therefore be used and comparisons made with greater accuracy.

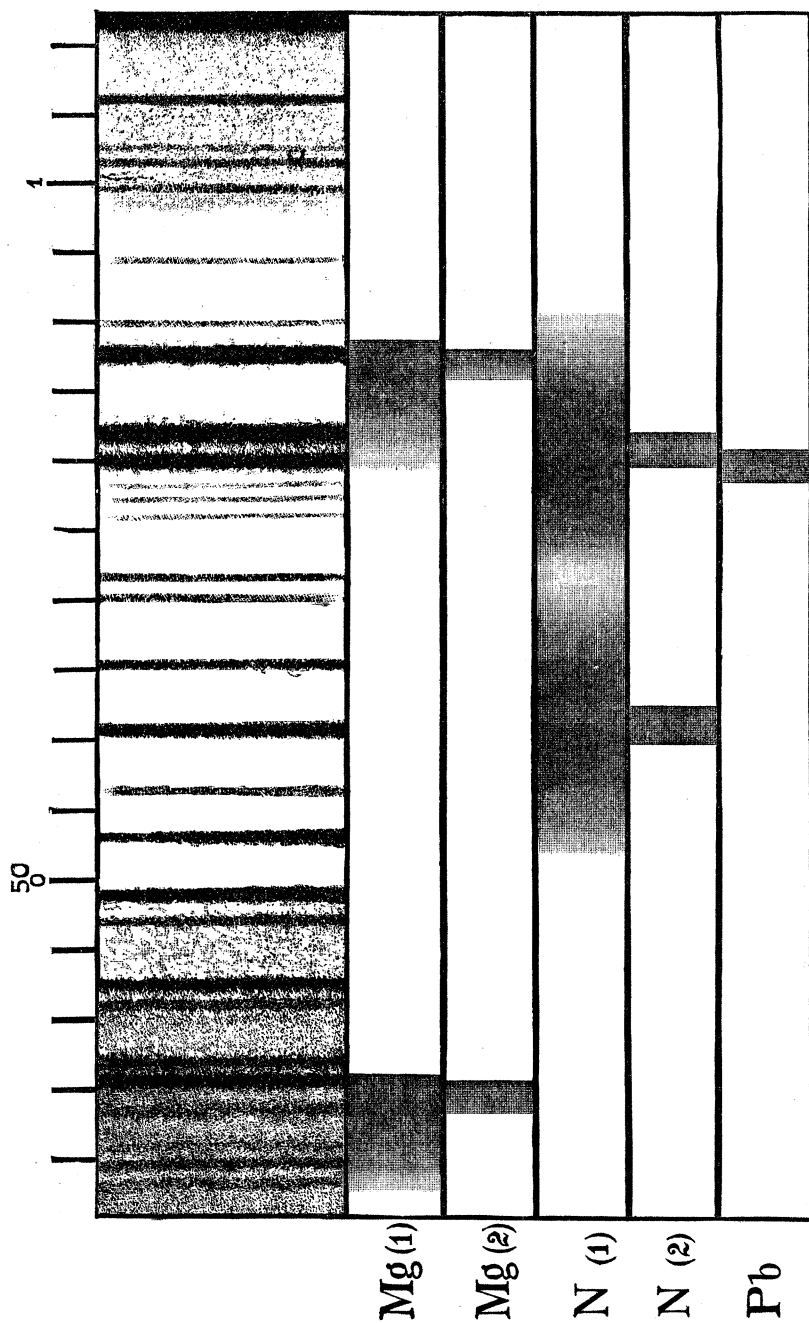


FIG. 1.—Comparison of the spectra of magnesium, nitrogen, lead, and Sun. Mg (1) and N (1) are as observed with a wide slit.  
(The scale is that of Rowland's photographic map.)

Four prisms and an observing telescope magnifying about thirty times were first used with the new conditions, and it was then found that the magnesium fluting was a little less refrangible than the nitrogen line. In this case the magnesium spectrum was obtained by burning magnesium in front of the bulb, and the non-coincidence with the nitrogen line was put beyond doubt by observing the two spectra simultaneously. This was further confirmed with the Rowland grating, the magnifying power employed being about fifty-five times.

Comparisons with the solar spectrum were then made, with the result shown in fig. 1.

The solar spectrum shown in the drawing is from an enlargement of Rowland's map of the region in question, and the positions of the fluting of magnesium and the lines of nitrogen and lead are as determined with four prisms and confirmed with the Rowland, which differs from Ångström's scale by one division; *e.g.*, 5007.5 on Rowland's scale is equivalent to 5006.5 on Ångström's. (This difference was determined by a comparison of twelve lines of iron mapped by Thalén with the corresponding solar lines shown in Rowland's map.) Two spectra of nitrogen are shown in the map, the first one, that seen when the small jar was used and the slit was rather wide; and the second, that seen with the jar spark in rarefied air and the slit as narrow as possible. In the first case the lines are very broad and begin to fade away rather suddenly on both sides. Two spectra of magnesium are also shown, one with the slit wide and the other with it narrow.

It will be seen that when the slit is rather wide the haziness of the less refrangible nitrogen lines overlaps the first maximum of the magnesium fluting, when seen with the same slit. This is the same whether magnesium or platinum poles were used for the air spark, and this shows that the apparent coincidence is not due to the remnant of the magnesium fluting being superposed on the air lines. The importance of using a narrow slit and a spark with large jar, preferably in air at a reduced pressure, for comparison with the nebulae is, therefore, obvious.

The results given are not to be absolutely relied upon, as there may be slight errors, due to the various light sources not being perfectly in the line of collimation. It has been found, for example, that a change of 111 minutes of arc in the direction of the beam from the siderostat displaces the lines about two divisions of Rowland's scale, or more than the difference between the positions of the chief nebula line and the fluting of magnesium as determined by Dr. Huggins. Every precaution was taken, however, to ensure the accuracy of the observations. The beam from the siderostat was first directed on the slit, and the spark and lens placed in the same direction by adjusting

their shadows on the slit plate. The slit was made as narrow as the luminosity of the spark would allow.

It was also noticed during the observations that errors may be introduced by the insensible motions of the eye in front of the slit. With a spectroscope having one flint glass prism of 60° and a telescope magnifying about fifteen times, the displacement of the lines due to this cause as referred to the cross wires was found to amount to as much as forty units, or twice the distance between the magnesium fluting and the less refrangible nitrogen line. With the Cooke spectroscope having eight prisms the displacement was not more than twenty units. Pinholes of various sizes were placed in front of the eyepiece, but the displacement was not at all diminished by this. The motion of the lines over the pointer was found to be quite rhythmical and to keep time with the beating of the heart.

No doubt this displacement could be abolished by perfect focussing, but the construction of instruments generally does not admit of the focussing of the cross wires, and even if there be an adjustment, as there is in the instrument used by me, one condition is only good for one observer.

These experiments, therefore, show that many precautions have to be taken before the coincidence or non-coincidence of one line with another can be determined with absolute certainty even when large dispersion and stable laboratory conditions are employed.

The general results of the laboratory comparisons may be briefly stated thus:—

	Huggins.	Thalén.	Liveing and Dewar (1880).	Liveing and Dewar (1888).	Lockyer.
Mg fluting.....	5006·5	..	5000	5006·4	5006·5
N line.....	5004·6	5005·1	..	..	5005·1
Pb line.....	5004·5	5004·6	..	..	5005·0

It must be remembered that ordinary observatory conditions are not nearly so favourable for accurate measurements of the positions of lines in spectra as laboratory ones. In the first place, the apparatus is not so stable, and must of necessity be in motion, and again, the collimator of the spectroscope with its slit exactly central must be demonstrated to be absolutely in the optic axis of the telescope before a measurement can be taken as final.

Two series of observations should therefore be made, one with the spectroscope in one position, and the other when it has been turned

through  $180^\circ$ . There is no statement in Dr. and Mrs. Huggins's paper that this has been done.

Finally, I may point out that with the above values, and assuming that the nebula line exactly coincides, as Dr. Huggins says that it does, with the least refrangible of the nitrogen double, the difference in position between it and the magnesium fluting is less than a quarter of the distance between the two D lines, and I have shown that this difference may easily arise from instrumental errors.

### *C. Observations by a New Method.*

The laboratory work having shown the numerous sources of error connected with observations where great accuracy is attempted, it seemed to me that it was quite hopeless to attempt very accurate observations of nebulae in the ordinary way, where the conditions are not nearly so favourable as in the laboratory.

I have already pointed out that unless it can be demonstrated that the collimator of the spectroscope is absolutely in the optic axis of the telescope employed, one series of observations alone is worthless. Again, the greater the dispersion employed, the greater generally will be the weight of the spectroscope, and the less the stability of the apparatus. Finally, as the telescope must necessarily be in motion, the conditions are constantly liable to change by the varying dispositions of the various parts of the apparatus.

It struck me that these difficulties could be to a great extent overcome by the use of a siderostat, in which case a spectroscope of any weight could be employed, as it was no longer necessary that it should be in motion. To test this method, arrangements were made for observing the spectrum of the nebula in Orion. A 12-inch siderostat and the 10-inch object-glass of the Science Schools equatorial were employed, in conjunction with an optically perfect Steinheil spectroscope belonging to the Physical Laboratory, and placed at my disposal by Professor Rücker.

The observations commenced on November 27th.

The following account is based upon the records in the note book, further explanatory additions having been made where necessary.

*November 27th.*—The 10-inch object-glass from the equatorial was supported in a semi-circular wood block, on an adjustable lantern tripod, which was sunk about 6 inches in the ground and the top perfectly levelled. By carefully sighting a lamp supported at the siderostat, the collimator of the spectroscope was placed in a line with it. The object-glass was then put in proper line, and adjusted by observations of Aldebaran with a reflecting eyepiece, which was supported in front of the slit, and so arranged that when an object was in the centre of the field it was also on the slit. Aldebaran was

also used for adjusting the object-glass at the proper distance from the slit. The ordinary cross-wire eyepiece of the spectroscope being replaced by the bright line micrometer, the prisms were adjusted at minimum deviation for  $\lambda$  500 by observing the spectrum of magnesium ribbon burning in a spirit lamp in front of the centre of the mirror. These preliminaries being completed, the work with the nebula was commenced.

The nebula was first brought upon the slit by means of the reflecting eyepiece, and the observation was attempted with four prisms, but unsuccessfully, as the night was not good and the nebula was low, so two were removed. When this was done, the three principal lines were seen remarkably well, and a very narrow slit could be used. The chief line was made coincident with the illuminated pointer; magnesium ribbon was then burned at the centre of the mirror, and with this dispersion the coincidence between the nebula line and the least refrangible maximum of the magnesium fluting appeared perfect. These observations were made independently by Messrs. Fowler and Baxandall, and Lieutenant Bacon, R.N., temporarily attached to the Science Schools, but in no case was the nebula line seen more refrangible than the magnesium fluting. Another prism was then added, and set to minimum for  $\lambda$  500.

Absolutely the same result was obtained. The burning magnesium used for comparison was removed from the front of the mirror and placed directly in front of the slit, but still the same result was obtained. The brightness of the nebula lines with three prisms made it evident that another prism might be added.

The magnifying power of the telescope employed was sixteen, and the dispersion C to H with three prisms was  $6^{\circ} 32'$ .

*November 28th.*—The observations of the Orion nebula were repeated with similar arrangements to those employed on the previous evening, the fourth prism being now added. The spectrum was very well seen when the nebula was on the slit, but it was very difficult to keep it on, as, in consequence of the looseness of a screw, as it was subsequently found, the siderostat clock worked badly.

One comparison was, however, made by Mr. Fowler, using the same micrometer eyepiece as before and a very narrow slit. The nebula line and the less refrangible maximum of the magnesium fluting were found to be perfectly coincident.

Arrangements had been made during the day for burning magnesium, so as to get parallel rays from it. The method is shown in fig. 2, and consists of a collimator placed in front of the object-glass. When burning the magnesium, a card, with a hole in the centre of the same diameter as the collimating lens, was placed in front of the 10-inch object-glass to keep out stray light. At the spirit lamp end of the tube was a piece of tin foil with a pin-hole at

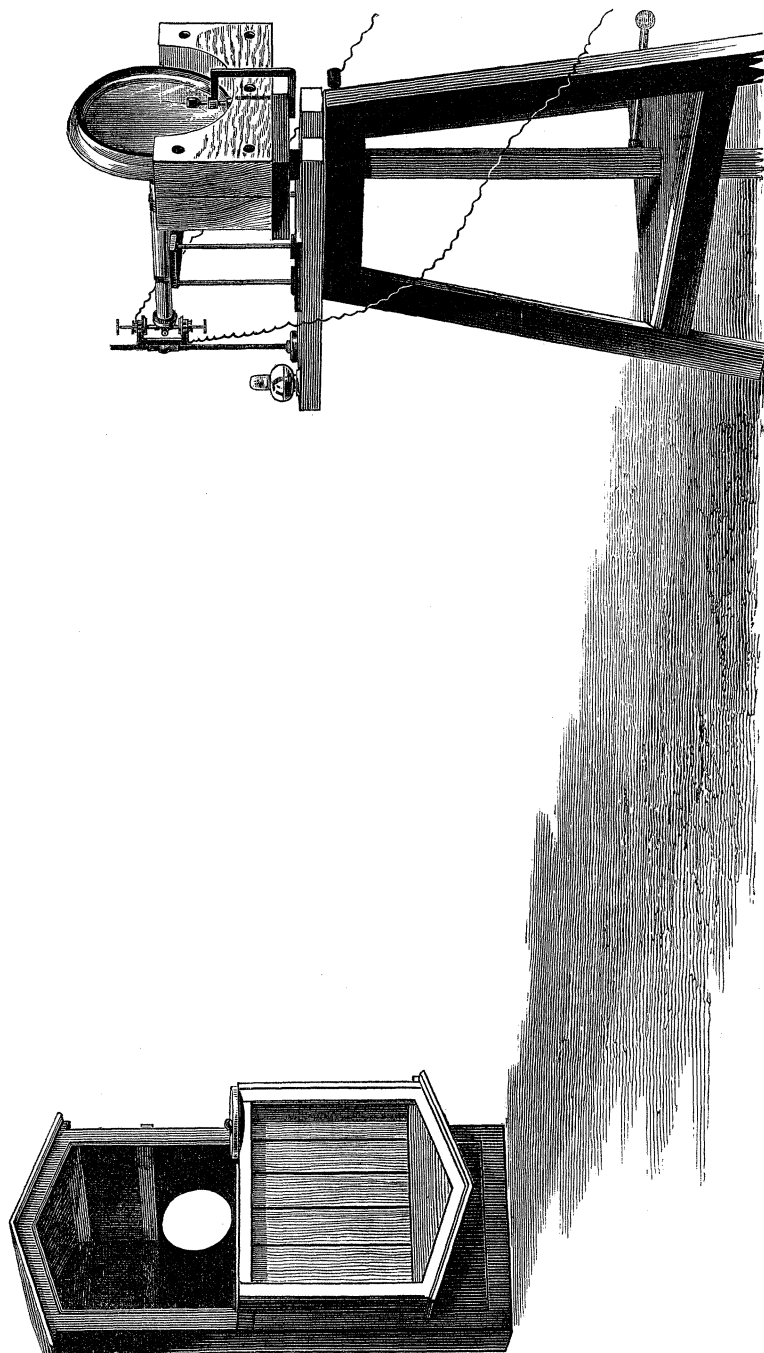


FIG. 2.—Preliminary arrangement of apparatus for observing the spectra of the heavenly bodies by the use of the siderostat. The 10-inch object-glass is supported on an adjustable stand between the siderostat and the spectroscope, the collimator of which is directed accurately to the centre of the mirror. The small collimator between the object-glass and the siderostat is for obtaining comparison spectra either from the flame of a spirit lamp or from the electric spark. The wires leading to the spark-stand pass through an opening in the side of the hut containing the spectroscope and the induction-coil.

the centre. The image of this was focussed on the slit of the Steinheil, and when the magnesium was burning the spectrum was well seen.

*November 29th.*—During the day the siderostat was put in order.

The position of the collimator of the Steinheil was tested by opening the slit very wide, and burning magnesium at the centre of the siderostat mirror (the mirror being temporarily removed for this purpose). The image of the slit fell exactly in the centre of the collimating lens, so that no alteration was necessary.

An observation was also made of the displacement of the magnesium fluting brought about by moving the spirit lamp in which the magnesium was burned away from the centre of the mirror. It was found that if the lamp were moved more than two inches on either side the spectrum ceased to be visible. Between the two extreme positions (*i.e.*, 2 inches on each side of the centre), the displacement produced was about one-third of the distance between the first and second maxima of the magnesium fluting.

The rough collimator that had been previously used was replaced by the collimator of a student's spectroscope, the slit of which was adjustable both for length and breadth. This was supported on a light iron tripod, so that, when in position, it would prevent very little light from the siderostat passing through the object-glass. By this arrangement the spectra of magnesium and the nebula could be superposed, it being intended to obtain the magnesium fluting in this case from a quantity spark between magnesium poles. An enlarged image of the secondary slit is, of course, formed on the slit of the Steinheil spectroscope.

A complete plan of the apparatus, drawn to scale, and showing some of the principal dimensions, is given in fig. 3. The Steinheil spectroscope employed has a circular table, 28 inches in diameter, supported on a tripod stand weighing about eighty pounds. The collimator and observing telescope are each about 20 inches long, and have object-glasses  $1\frac{3}{4}$  inches in diameter. The prisms have faces  $2'' \times 2''$ , three of them having an angle of  $45^\circ$ , and one of  $60^\circ$ , each one being supported on a stand provided with levelling screws. With the four prisms the dispersion from A to H is  $10^\circ$ .

The reflecting eyepiece which was used to act as a finder was the ordinary one used with the 10-inch equatorial, and could be lifted out of its supports and put back again at pleasure.

No work could be done in the observatory this evening on account of fog.

*November 30th.*—Commenced work by adjusting the object-glass and the collimator in front of it.

The accuracy of this adjustment was checked by a comparison of *b* the spectrum of the Moon with *b* in the spectrum of magnesium



burning behind the secondary collimator. There was perfect coincidence between the lines. Four prisms were used for the comparison, and the centre of the Moon's disc was thrown on the slit.

Everything being now in perfect adjustment, the nebula was turned to, and three good comparisons made of the chief line and the magnesium fluting, the magnesium being burned behind the secondary collimator. The pointer was displaced and readjusted in each observation. In each case the coincidence with the least refrangible maximum appeared perfect. These observations were made by Mr. Fowler and Lieutenant Bacon. In order to further test the result obtained, Mr. Fowler put the pointer of the micrometer exactly on the nebula line, and left it for Lieutenant Bacon to say how its position was with respect to magnesium; again it was perfectly coincident.

Lieutenant Bacon made three independent comparisons, the position of the pointer being changed each time, and twice found coincidences with the least refrangible maximum, whilst once the nebula line appeared to be on the right-hand edge of the same maximum. Mr. Gregory also made one comparison which confirmed the above results.

*December 1st.*—The object-glass having been adjusted by means of Aldebaran as before, the secondary collimator was put in position, and the magnesium spark from a quantity coil put behind the slit. With this arrangement a comparison of the nebula line with the lines of nitrogen could also be made. The collimator was adjusted by means of  $b$ , as seen in the Moon and in the magnesium spark.

The pointer of the micrometer was then put upon the F line in the Moon, and the nebula was afterwards brought upon the slit. The two lines were coincident, showing the probable accuracy of the adjustments.

Three comparisons were made of the nebula line with magnesium by Mr. Fowler, the pointer being displaced each time; in each case the coincidence was perfect.

Comparisons with the nitrogen lines showed the nebula line to be a little less refrangible.

I made the comparison twice, and in each case the coincidence with the magnesium fluting was perfect. In one case I saw the pointer of the micrometer, the nebula line, and the nitrogen lines at the same time; the pointer was on the nebula line, but both appeared to the right of the nitrogen double.

Finally, Mr. Fowler put the pointer on the nebula line, Lieutenant Bacon agreeing with him as to the setting. Then I made the following comparisons:—

- (1.) With the nitrogen lines. Result, pointer to the right.
- (2.) Magnesium burning behind slit. Result, coincidence perfect.

(3.) Magnesium burning at the centre of the siderostat. Result, again perfect coincidence.

It was found that magnesium burning at the centre of the siderostat was coincident with magnesium burning behind the secondary slit, thereby showing the accuracy of the adjustments.

In all these observations the nebula line was seen to be sharper on the right-hand edge than on the left, and it was irregularly bright along its length, as in the Westgate observations.

The observations have left no doubt in my mind as to the coincidence of the chief nebula line with the magnesium fluting, under such conditions that at the same time the coincidence of the F line of hydrogen with another nebula line was demonstrated.

Lieutenant Bacon and my assistants concur in this view. Even with four prisms the observations are by no means easy, and are very delicate, but it is important to note that in no observation was the nebula line found more refrangible than the magnesium fluting, and if the optical conditions were imperfect it seems hardly likely that an error in the same direction would be reproduced on four different nights, the apparatus being set up afresh each time.

Arrangements are in progress for repeating the observations with apparatus furnished with screw adjustments.

There is one more test of the accuracy of the adjustments which might have been applied had I thought of it in time. So far the test relied on has been to see that the lines seen in the spectrum of magnesium burning at the centre of the mirror were coincident with those seen when the magnesium was burned behind the secondary slit. In one case the light passed through the object-glass only, while in the other it passed through the object-glass and secondary collimator. When the observations are repeated, it is intended to further test the adjustments by forming an image of the flame at the mirror upon the secondary slit, so that in both cases the light will pass through the collimator and object-glass. If the lines are still coincident, the accuracy of the adjustments will be still further demonstrated.

#### IV. FLUTED CHARACTER OF THE CHIEF NEBULA LINE.

Dr. and Mrs. Huggins state that the chief nebula line is perfectly sharp and well-defined. This necessitates my giving in reply a complete account of those recorded observations, which, coupled with my own, have led me to the opposite conclusion, namely, that the line is often noticed ill-defined at the edges, chiefly on the blue side, and in some parts of the nebula in Orion presents even more unmistakable indications that it is the remnant of a fluting.

Certain references in the paper suggest that it may be well that I

should briefly state what I understand by a fluting, and I cannot do this better than by referring to observations of a candle flame which anyone can make. A pocket spectroscope and a lens are all that are needed to follow my remarks. If the image of the base of the flame be projected on to the slit, bright flutings are seen in the green (near *b*), citron, blue, and violet. That in the green is the brightest, and is seen to consist of three apparent bright lines with faint fringes on their more refrangible sides. The different members of the group gradually diminish in brightness, the least refrangible being the brightest. Such a group as this I look upon as a *compound* fluting, and each member itself as a *simple* fluting, since with high dispersion the fringes break up into series of fine lines very close together. If now the image of the flame be gradually raised, so that the base passes off and portions nearer the centre are brought on to the slit, the fainter members of the group gradually disappear, and when a certain point is reached only the brightest, least refrangible, simple fluting is left. This I look upon as the "remnant of a fluting," whether the fluting was in the first instance simple or compound.

The compound fluting of magnesium near 500 is very similar to that of carbon. It consists of a series of bright lines of gradually diminishing brightness and increasing distances apart towards the more refrangible end, and each has a fringe on the more refrangible side. The first maximum (the least refrangible) is brighter than the others, and the fringe close to it is brighter than the second maximum, and so when "the remnant of the magnesium fluting near 500" is referred to, the first maximum with that portion of its fringe which is brighter than the second maximum is meant.

Before I give the observations of the character of the chief nebula line in historical sequence, I quote Dr. Huggins's statement:—"My own observations of the line, since my discovery of it in 1864, with different spectroscopes up to a dispersion equal to eight prisms of 60°, show the line to become narrow as the slit is made narrow, and to be sharply and perfectly defined at both edges."

The following are the first recorded observations:—

In 1864, the spectrum of the Dumb-bell nebula in Vulpecula was observed, and it was noted\* that the light of this nebula, after "passing through the prisms, remained concentrated in a bright line, corresponding to the brightest of the three lines represented in fig. 5, Plate X. *This line appeared nebulous at the edges.*"

Similarly, it was recorded in 1866 of the spectrum of General Catalogue No. 4403:—† "The spectrum of this nebula indicates that it possesses a gaseous constitution. One bright line only was

\* 'Phil. Trans.,' 1864, p. 441.

† 'Phil. Trans.,' 1866, p. 385.

seen, occupying in the spectrum apparently the same position as the brightest of the lines of nitrogen. *When the slit was made as narrow as the intensity of light would permit, this bright line was not so well-defined as the corresponding line in some of the other nebulae under similar conditions of slit, but remained nebulous at the edges.*" An observation of the spectrum of General Catalogue No. 4572,\* also made in 1864, led the observer to record:—"The spectrum of this nebula consisted of one bright *nebulous* line of the same refrangibility as the brightest of the lines of nitrogen," and in the same paper we read:—"One bright line only was distinctly seen, of apparently the same refrangibility as the brightest of the nitrogen lines. *This bright line appeared by glimpses to be double.* Possibly this appearance was due to the presence near it of a second line."

These observations show conclusively that the chief nebula line has not always been described as "sharply and perfectly defined at both edges," to use Dr. Huggins's language of 1889, and to no one should this fact be more manifest than to Dr. Huggins, since the above observations were made by him.

Secchi, one of the first observers of nebular and stellar spectra, in observations of some planetary nebulae made in 1866,† saw the three principal lines, and noted that "the planetary nebula in Andromeda has the lines above named, but the principal one is a little diffused."

The observation relating to the presence of a second bright line very near to the chief nebula line might have been of considerable importance, and have afforded an almost crucial test of the validity of my identification of the line. This second line might well have been the second maximum of the magnesium fluting, but Dr. Huggins's statement as to its position is so loose as to make it impossible for me to say whether such is the case or not.

I should, however, have been unjustified in relying upon Dr. Huggins alone; and it will be seen from what follows that nearly all observers of nebula spectra have noted at some time or other that the chief nebula line appeared undefined at one edge, as if it were part of a fluting.

In 1871 Vogel made some observations of the spectra of nebulae.‡ I have noted that in 1864 Dr. Huggins observed only one bright line in the spectrum of the Dumb-bell nebula, and recorded this line as *nebulous* at the edges. Vogel's observations of the spectrum of the same nebula in 1871 agree, as regards the character of the line, in every respect with that of Dr. Huggins.

The following is Vogel's description:—"Sehr heller grosser Nebel der unter dem Namen Dumb-bell bekannt ist. Das Spectrum desselben

\* 'Phil. Trans.,' 1866, p. 386.

† 'Bullettino Meteorologico,' 31st Oct., 1866.

‡ 'Bothk. Beob.,' Leipzig, Heft 1, 1872, p. 56.

wurde am 21 Mai, 1871, untersucht, es besteht aus zwei Linien, von denen die erste mit der Stickstofflinie (Wellenlänge 500·4 Milliontel Millimeter) coincidirt; diese Linie erscheint aber hier breiter als in den Spectren der planetarischen Nebel und ist besonders nach dem violetten Ende des Spectrums SEHR VERWASCHEN."

Here, then, it is again explicitly stated that the nebula line was considerably ill-defined on the violet edge.

Bredichin made a series of observations of the three nebula lines in 1877, and he noted also that the chief line was less defined on the blue edge. In the words of this observer, "se presentait comme une bande, une peu plus claire vers le rouge."\*

The following is the description of the chief nebula line, as seen in the Orion nebula, given by Mr. Maunder in 1884:—†

"The line  $\lambda$  5005 was examined with this latter dispersion (two-prism train), the slit being very narrow, and was seen to be a single line. None of the lines in the spectrum of the nebula are, however, very sharp.  $\lambda$  5005 showed a faint fringe mainly on the side nearer the blue."

It must be borne in mind that as these observations of the undefined condition of the blue edge of the nebular line were made before special attention had been directed to it by my paper of November, 1887, they were *absolutely unbiassed*. Prior to 1887, no one had suggested that the line might be the remnant of a fluting. Indeed, Dr. Huggins contended for a line of an unknown form of nitrogen.

I have already quoted Dr. Huggins's present declaration, that since his discovery of the nebula line in 1864 he had always observed it as sharply and perfectly defined at both edges, by which assertion he practically repudiates his own published observations. But Dr. Huggins has done more than this; he has put himself to the trouble of communicating with other observers of nebula spectra with a view of obtaining their opinions as to the character of the chief line. I need only refer to Dr. Huggins's correspondence with Professor Vogel, who wrote,‡ in answer to a letter from him and in support of his view:—"Beeile ich mich Ihnen mitzutheilen, dass meine langjährigen Beobachtungen über die Spectra der Gas-Nebel vollkommen mit den Ihrigen darin übereinstimmen, dass die Nebellinie  $\lambda$  5004 schmal, scharf und NICHT VERWASCHEN IST." With reference to the observation of Dr. Vogel as to the undefined character of one edge of the nebula line, previously referred to in this reply, Dr. Huggins remarks as follows:—"In an early observation of the Dumb-bell nebula, Professor Vogel, indeed ('Beobachtungen zu Bothkamp,' p. 59, 1872), describes this line as less defined towards the violet side. In a letter

\* 'Annales de l'Obs. de Moscou,' vol. 3, 1877, p. 120.

† 'Greenwich Spectroscopic Results,' 1884, p. 5.

‡ 'Roy. Soc. Proc.' vol. 46, p. 53.

(April 3, 1889), Professor Vogel says this appearance of the line was probably due to a slit not sufficiently narrow. He says that he re-examined this line in his observations with the great Vienna refractor, and that it did not then appear otherwise than defined and narrow."

I fancy that Dr. Huggins and Professor Vogel must know that widening the slit does not generally cause a well-defined line to become less defined *on one side only*. Again, the fluting would very probably be seen little better with the Vienna refractor than with that at Bothkamp; for I find that the brightness of the nebula in the former is to that in the latter only about as 13 to 10.

Since my paper of November, 1887, was written other observers besides Dr. and Mrs. Huggins have had their attention directed to nebular spectra, with special reference to the character of the chief line.

My first observations of the nebula of Orion from this point of view were made at Westgate-on-Sea in October, 1888, by means of a 12-inch mirror that had been kindly placed at my disposal by Mr. Common. The image of the nebula being allowed to float slowly over the slit, I distinctly got the impression that the line in question varied in its behaviour from the other lines, and that at the points where it was brightest it extended most towards the blue end of the spectrum. The observations were repeated at Kensington with the 10-inch equatorial by Mr. Fowler, Demonstrator of Astronomy, and Mr. Baxandall, and they arrived at the conclusion that the chief line had a decidedly fluted appearance.

This observation is further borne out by Mr. Taylor, who, referring to an observation made in November, 1888,\* states:—

"The 5001 line is by far the brightest in the spectrum. It is never seen sharp, but, with the narrowest slit, always has a fluffy appearance, this being much more marked on the blue than on the red edge. This was most carefully examined for evidence of structure, but the line was always found to be single, and no decided evidence of fluting structure could be made out." It is clear from this observation that the line fades away towards the violet end of the spectrum, although the actual compound structure of the magnesium fluting is not visible. I shall presently have to refer to an experiment which shows that the compound structure would not be likely to be visible.

I have quite recently (October 29) observed the spectrum of the nebula in Orion with my 30-inch reflector at Westgate-on-Sea, using an enlarged form of pocket spectroscope with a dispersion which does not split D, and the observation is, to my mind, final. I found that in certain parts of the nebula the lines were knotted, and in others broken; but in the former case, whilst the F line thickened

\* 'Monthly Notices, R.A.S.,' vol. 49, p. 125.

equally on both sides, the chief line thickened only on the more refrangible side. This result is shown in fig. 4.

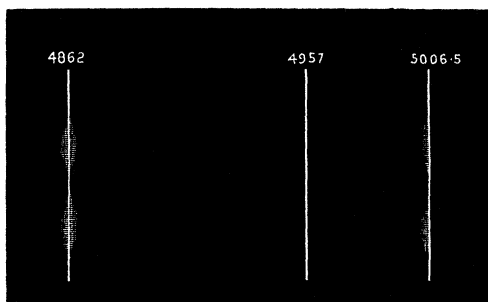


FIG. 4.—Diagram showing the appearance of the three principal lines in the spectrum of the nebula in Orion as observed in the Westgate 30-inch reflector.

This was confirmed by Messrs. Fowler and Baxandall at Kensington, with the 10-inch equatorial on October 31st and November 1st, and again by Mr. Fowler, with the 30-inch, on November 2nd. It may be noted also that I got momentary glimpses of many bright lines between F and G on October 31st. Messrs. Fowler and Coppen have since made some very careful observations of the Ring nebula in Lyra, and also record the chief line as having a fringe on the more refrangible side. A line less refrangible than 500 in the neighbourhood of *b* was suspected; this may turn out to be the carbon fluting near 517: the absence of the hydrogen line in the 10-inch was important as indicating that the nebula is in an advanced stage of condensation, approaching that of the nebula in Andromeda.

In the observations with the siderostat arrangement, as pointed out in the extracts from the observatory note-book, the chief line was noted by Mr. Fowler and Lieutenant Bacon to have a decided fringe on the more refrangible side.

It may be remarked that high dispersion is not so likely to show the fluted character of the chief line as low, for the more the fringe is dispersed the fainter it must become.

In consequence of the brilliancy of the Orion nebula, the fluted appearance of the chief line would be more manifest than in any other nebula, and the absence of the fringe when the line is seen in the spectra of fainter nebulae is therefore not antagonistic to the view that the line may be the remnant of the magnesium fluting. This must not be misinterpreted. Given two nebulae, exactly alike in every respect but temperature, then the line, if visible in both, would appear more like a compound fluting in that nebula of which the temperature

was lower, and would become more like a line as the temperature was increased.

But this is not all; a greater number of collisions per unit volume at the same temperature would increase the visibility of the effects, and greater brightness in a nebula may proceed from this cause as well as from a less distance. We should not, therefore, expect to see the fluting, even if its existence be conceded, in all cases, and the smaller the dispersion the better it will be seen, *ceteris paribus*. Experiments have been made here on the spectrum of magnesium when seen very faintly with moderate dispersion.

The conditions being such that the structure of the fluting near 500 was well visible when magnesium ribbon was burned in front of the slit, a sufficient thickness of neutral tint glass was introduced to reduce the brightness of the fluting until it was about equal to that of the chief line seen in the spectrum of the nebula in Orion. Under these conditions, the 500 fluting is only faintly visible and the secondary maxima entirely disappear. We get only the brightest, least refrangible member of the compound fluting, together with a simple fringe of light without structure on the more refrangible side. This experiment was shown at the Royal Society Conversazione in May, 1889, and a note upon it may be found on page 13 of the programme. The experiment has recently been repeated and fully confirmed with a four-prism Steinheil spectroscope. It was found best to adjust the dark glasses so that two or three of the maxima were seen when the magnesium was burning; then, when the magnesium was just dying out, only the least refrangible one, with a slight fringe, was seen.

The greater luminosity of the first maximum and its fringe has also been observed in another way. Magnesia, volatilised in the oxy-hydrogen flame, with the proportion of gases properly adjusted, gives the compound fluting pretty bright. If, then, the quantity of hydrogen be increased or diminished gradually, whilst the oxygen remains constant, the fluting gradually disappears, but the first maximum and its fringe are seen when all the others have disappeared.

Numerous photographs have also been obtained which show the first maximum brighter than any of the secondary ones.

These experiments not only show that the first maximum is brighter than the secondary ones, but further, that some of the fringe on the more refrangible side of it is also brighter. In observations of nebulae, therefore, if the chief line be due to magnesium only a very slight fringe would be observed unless the luminosity be sufficient to render visible some of the secondary maxima.

I have shown, therefore, that many records exist as to the fluted appearance of the chief nebula line—records that amply justify the

identification of it with the low-temperature magnesium fluting near 500, an origin that seemed most probable from my experiments on the spectra of meteorites. The fact that one or two published observations have now been practically withdrawn does not affect the main issue in the faintest degree.

Whatever the chemical origin of the line, the historical statement I have just given affords good grounds for believing that it is certainly a remnant of a fluting.

## V. CONCLUSION.

The facts recorded in this paper seem to me to demonstrate conclusively that the line under discussion is due as the induction suggested to magnesium.

High dispersion has been employed, and we now know that the line seen in the meteoritic glows is truly the remnant of the magnesium fluting. We further know that the nebula line is coincident with the edge of the magnesium fluting when the two are compared with a four-prism spectroscope and a high magnifying power, both nebula and magnesium being observed under absolutely the same conditions. Even if we accept Dr. Huggins's observation of 1868, the nebula line only differs in position from the magnesium fluting by a quarter of the distance between the D lines, and we know that many sources of error may explain that difference.

Finally, many observations, both new and old, show that the nebula line resembles the first maximum of the magnesium fluting in having a fringe on its more refrangible side, and I have shown that the spectrum of magnesium may be observed under such conditions that only the first maximum and its fringe are visible.

The discussion of the other lines is reserved for a further communication, as the work connected with them is not yet completed.

With regard to the concluding part of Dr. and Mrs. Huggins's paper, I have recently sent in communications to the Royal Society from which it will be gathered how independent the meteoritic hypothesis is of the visible radiation of magnesium in meteorites at the temperature of nebulæ. But whether the line referred to in this paper be due to magnesium or not, I am glad to find that Dr. Huggins has so far accepted the views which I have recently put forward as to admit in the paper under reply that the nebulæ may "represent an early stage in the evolutionary changes of the heavenly bodies," and that they may stand at or near the beginning of the evolutionary cycle so far as we can know it;\* whereas he formerly held that "the nebulæ which give a gaseous spectrum are systems possessing a structure, and a purpose in relation to

\* 'Roy. Soc. Proc.,' vol. 46, p. 59.

the universe, altogether distinct and of another order from the group of cosmical bodies to which our Sun and the fixed stars belong;”\* and that: “We have in these objects to do no longer with a special modification only of our own type of Suns, but find ourselves in the presence of objects possessing a peculiar and distinct plan of structure.”† I shall take a subsequent opportunity of showing how untenable is the view he now communicates, that, although the nebulae represent early evolutionary forms, they are at a high temperature and that the constituents of the mass are arranged in the order of their vapour densities. I refrain from discussing these points on the present occasion; but I may remark that if such a view were true, and we further accept the statements that the nebula line was seen in the comets of 1866–67 and that Nova Cygni probably exists as a planetary nebula of small angular diameter, we are driven to the conclusion that comets reduce their temperature as they approach the Sun, and that “new stars” get hotter as their luminosity diminishes.

“Note on the Spectrum of the Nebula of Orion.” By J. NORMAN LOCKYER, F.R.S. Received and read February 13, 1890.

In a former communication I gave in detail observations made by means of a siderostat, which seemed to put beyond all reasonable doubt the question of the origin and true wave-length of the chief nebula line. Although, as I stated in the communication referred to, I regard this question as one of secondary importance, I have commenced another series of investigations with a view of eliminating all possible instrumental errors. The new method has not been completely carried out, but a sufficient approximation to it has been reached to render the results obtained of some interest.

Using the siderostat, object-glass, and collimator as before described, the method in question consists in using a vacuum tube, giving the lines both of hydrogen and nitrogen in front of the slit of the collimator. The tube made for this purpose was found to have leaked when there was an opportunity of using it, so that the observations of hydrogen and nitrogen, in comparison with the nebula lines, have not been made in the same field of view at the same time. The hydrogen tube and an air spark with iron poles (iron poles being chosen in order to check the position of the nebula line near  $\lambda$  495) were, however, placed alternately in front of the slit of the collimator, and this enabled the observations to be made with almost equal accuracy. I give the following extract from the Observatory

\* ‘Roy. Soc. Proc.’ vol. 14, p. 42.

† ‘Phil. Trans.’ 1864, p. 442.

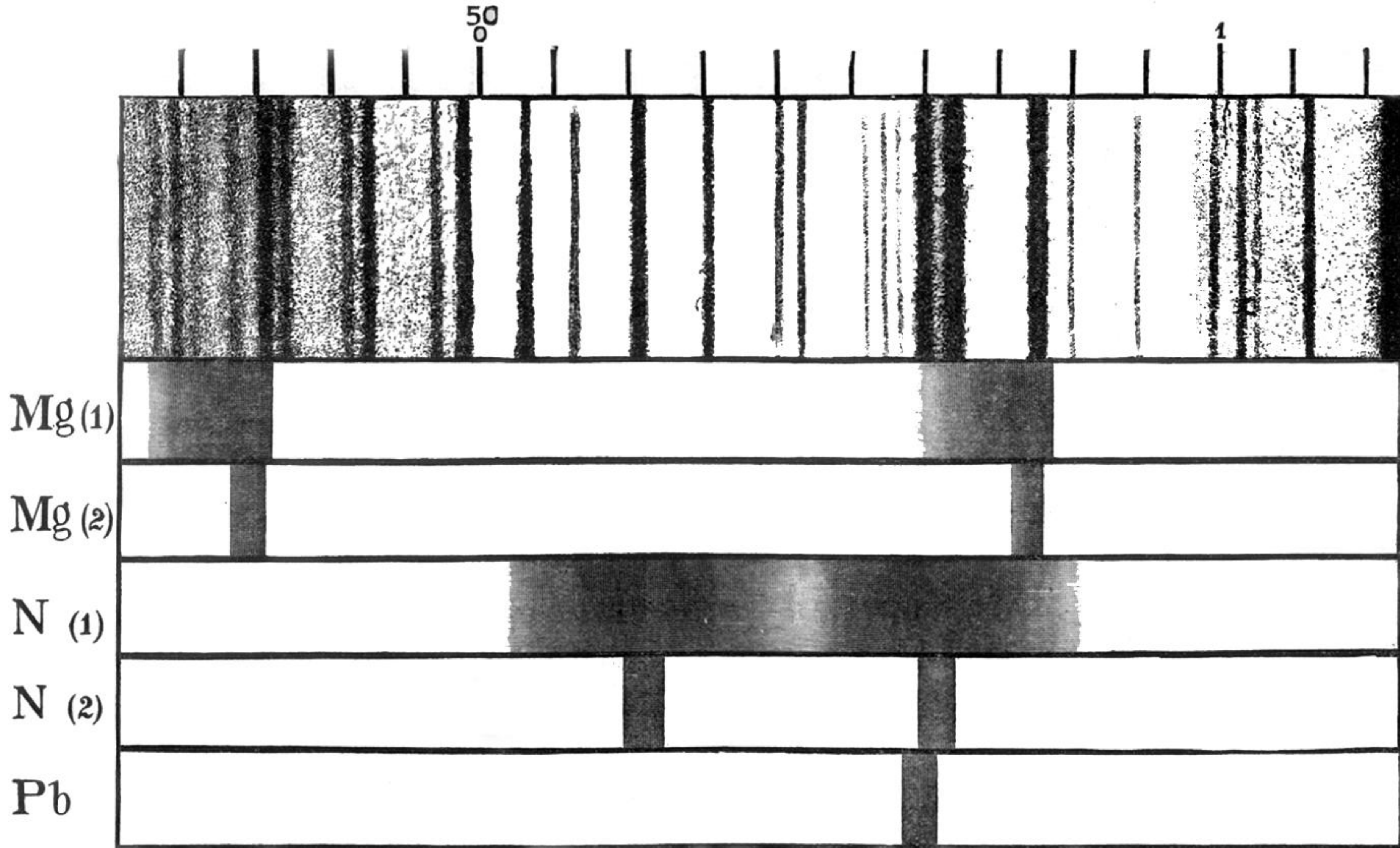


FIG. 1.—Comparison of the spectra of magnesium, nitrogen, lead, and Sun. Mg (1) and N (1) are as observed with a wide slit.  
(The scale is that of Rowland's photographic map.)

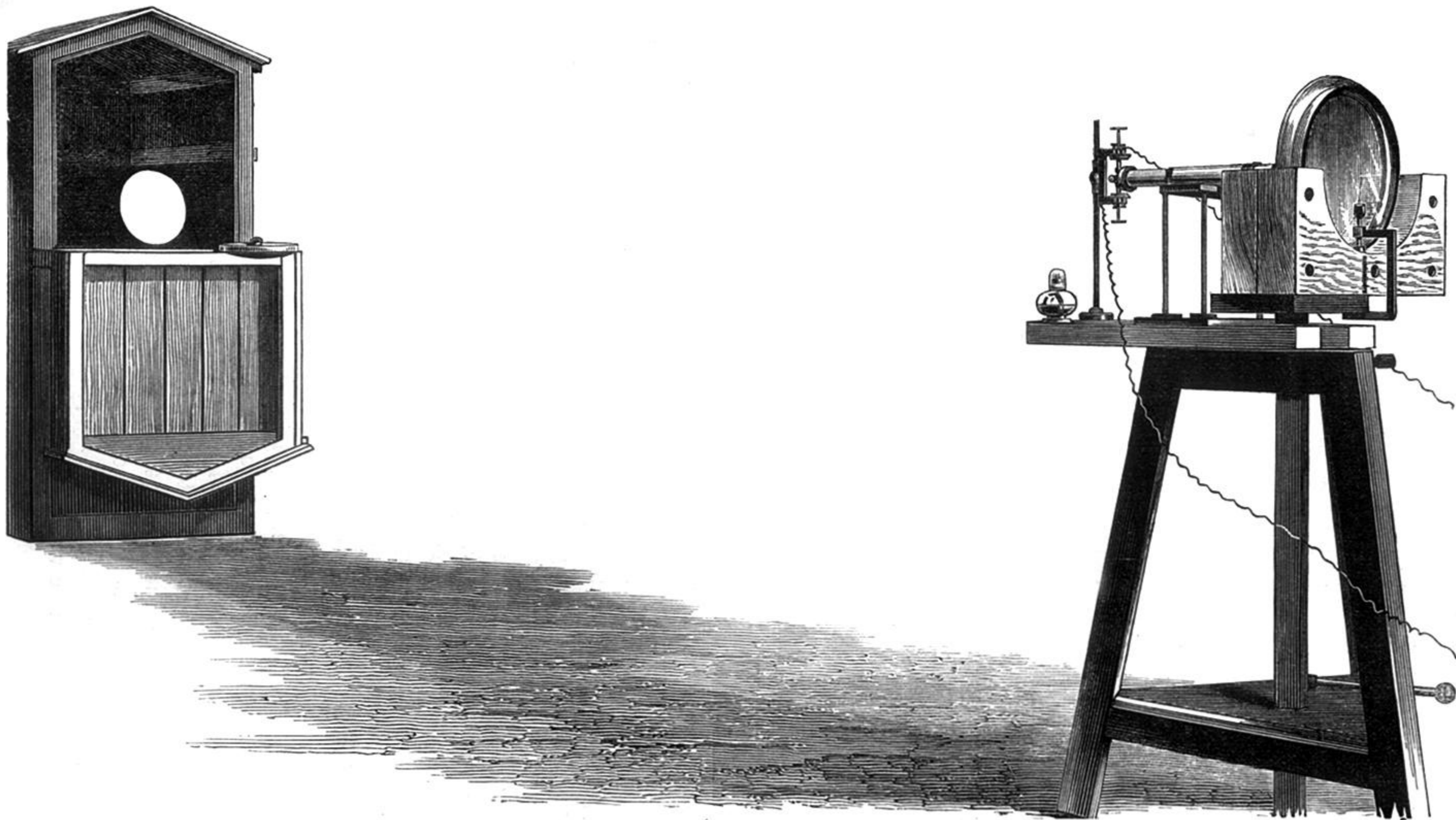


FIG. 2.—Preliminary arrangement of apparatus for observing the spectra of the heavenly bodies by the use of the siderostat. The 10-inch object-glass is supported on an adjustable stand between the siderostat and the spectroscope, the collimator of which is directed accurately to the centre of the mirror. The small collimator between the object-glass and the siderostat is for obtaining comparison spectra either from the flame of a spirit lamp or from the electric spark. The wires leading to the spark-stand pass through an opening in the side of the hut containing the spectroscope and the induction-coil.

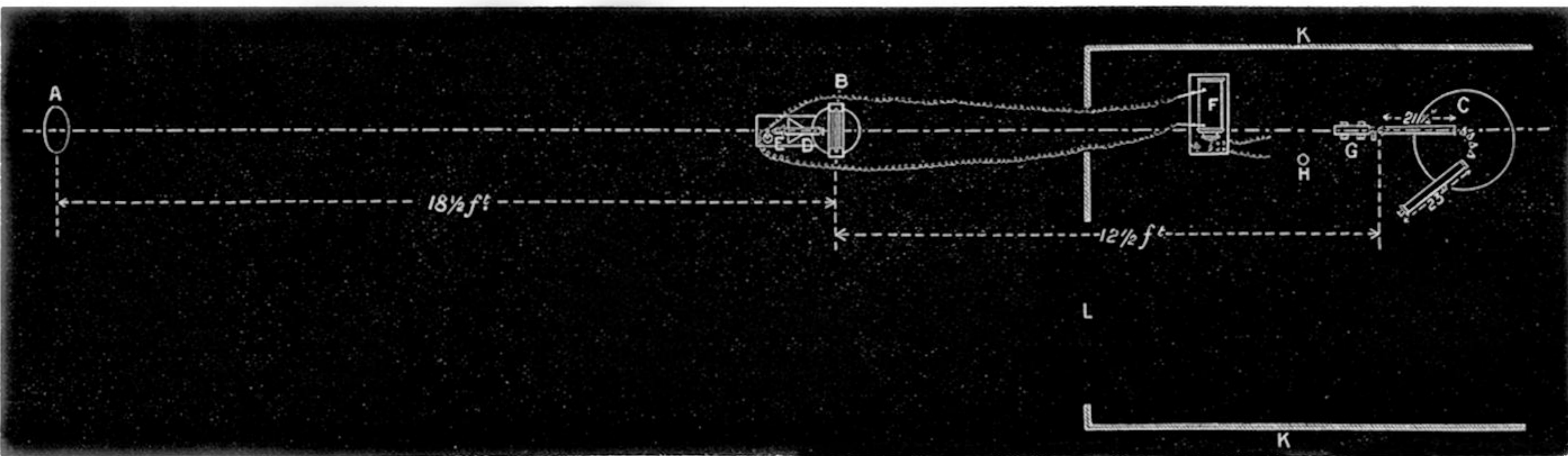


FIG. 3.—Plan of arrangements for observing the spectra of the heavenly bodies by the aid of a siderostat. A, siderostat; B, 10-inch object-glass and support; C, 4-prism Steinheil spectroscope; D, collimator for obtaining comparison spectra; E, spark stand; F, induction coil; G, reflecting eyepiece to act as finder; H, lamp for illuminating the pointer of the micrometer; K, wall of hut; L, doorway.

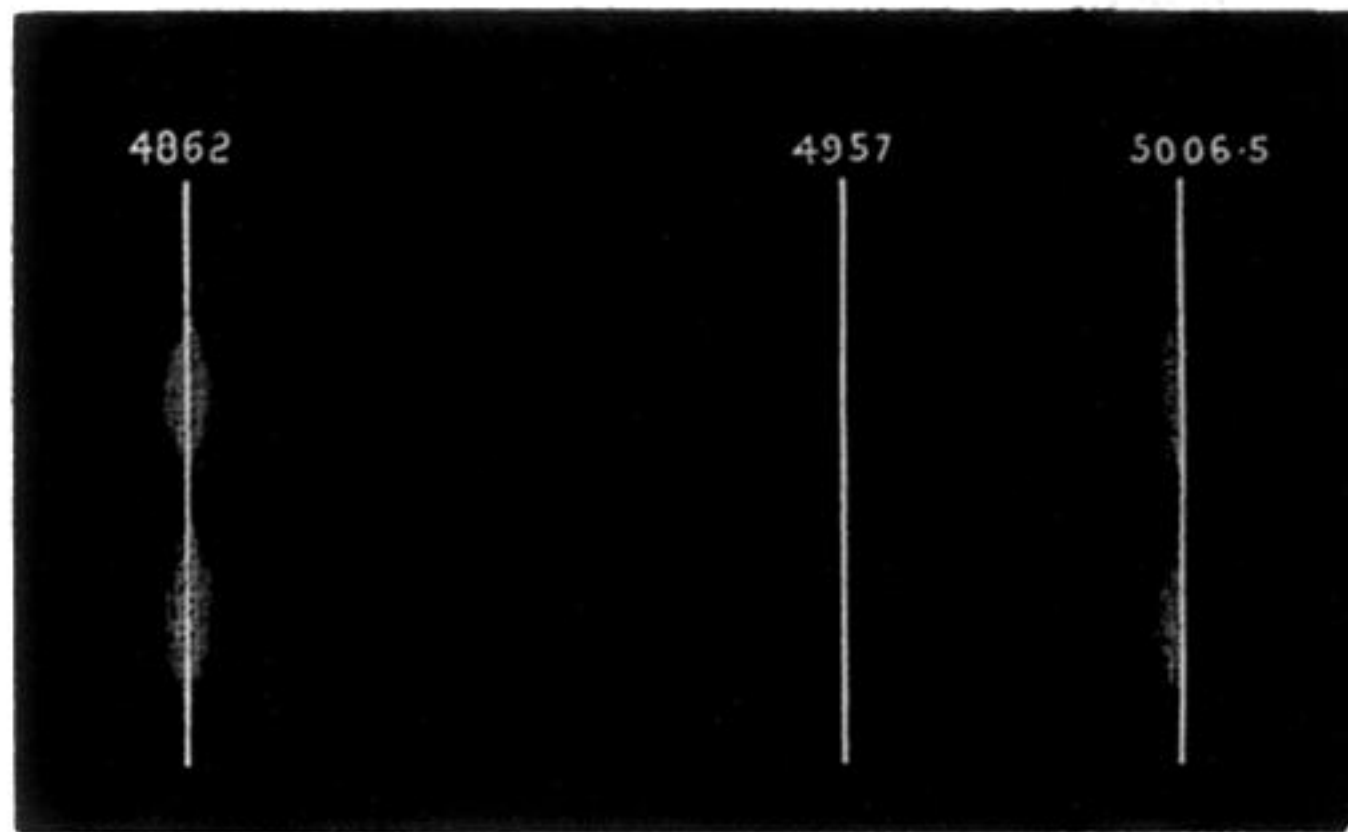


FIG. 4.—Diagram showing the appearance of the three principal lines in the spectrum of the nebula in Orion as observed in the Westgate 30-inch reflector.